Methyl Bromide *Alternatives*

USDA

Vol. 6, No. 1
January 2000

Inside This Issue

This issue and all back issues of the *Methyl Bromide Alternatives* newsletter are now available on the Internet at **<http://www.ars.usda.gov/is/np/mba/mebrhp.htm>**.
Visit the ARS methyl bromide research homepage at **<http:/www.ars.usda.gov/ismbmebrweb.htm>**.

This newsletter provides information on research for methyl bromide alternatives from USDA, universities, and industry.

Address technical questions to Kenneth W. Vick, USDA, ARS, National Program Staff, 5601 Sunnyside Ave., Beltsville, MD 20705–5139. Phone (301) 504-5321. Fax (301) 504–5987.

Address suggestions and requests to be added to the mailing list to Sharon Durham, USDA, ARS, Information Staff, 5601 Sunnyside Ave., Beltsville, MD 20705–5129. Phone (301) 504–1611, fax (301) 504–1641.

Managing Apple Replant Disease in Tasmania, Australia, Without Methyl Bromide

Apple replant disease is a significant problem in Australia and is currently held in check there with the use of methyl bromide. Apples are a major crop in the island state of Tasmania, with 1.5 million trees producing more than 47,000 tons of apples a year.

Orchards in Tasmania experience significant levels of apple replant disease. There 60 ha of orchard are replanted and of these, 35 ha are treated with methyl bromide before planting. This use accounts for 30–45 percent of Australia's methyl bromide use. With the 2005 deadline fast approaching for the methyl bromide phaseout, the need to find alternatives to methyl bromide cannot be overstated for this industry.

Gordon S. Brown, a research fellow at the Tasmanian Institute of Agricultural Research, conducted studies to determine the extent and severity of apple replant disease, the effect of the disease on fruit yield, and the role of possible antagonists to the disease.

"The focus was on nonchemical means of overcoming apple replant syndrome," said Brown. "In the absence of methyl bromide, it is probable the role of biological and cultural control practices will increase in managing replanting problems."

To determine the extent and severity of replant disease, a pot experiment was conducted using 11 soil samples, 10 from orchards and one from a nonorchard source. Each of the soils showed an improvement in shoot growth using soil sterilization, with the exception of the nonorchard soil. The severity of the disease varied among the sites, with the majority of plants showing more than a 50 percent reduction in growth due to apple replant disease.

The impact of replant disease on fruit yields was examined in two field trials started in 1997. Foliar area was measured at the end of the first season and fruit yield was measured in the second season. Foliar growth was reduced by 40 percent in nontreated soil, compared to soil treated with methyl bromide. Fruit yield showed some *small* reduction between the untreated fields and those treated with methyl bromide, but this amount was not statistically significant.

Possible Causes of Apple Replant Disease

Nematodes, fungi, and bacteria were each investigated for their contribution to apple replant disease. In a pot trial, it was determined that nematodes are not the *principal* cause of replant disease in Tasmania. However, it

seems the use of nematicides had some positive effect in 40 percent of the orchards. In four trials using fungicides, fungi were eliminated as causes of replant disease.

Bacteria, on the other hand, seem to be a primary cause of apple replant disease in Tasmania. In two sets of pot trials, the antibiotic streptomycin was incorporated into the soil prior to planting. In both sets of trials, growth of young plants significantly improved. But, streptomycin is expensive and is not registered for any agricultural crop in Australia, so it is not a viable alternative treatment for Tasmanian orchardists.

According to Brown, in the long term biological control, along with cultural and chemical control practices, will be important tools in the management of this problem. He also notes, "it is important, however, to develop a replanting system that is cost-effective, reliable, and maximizes early returns of high-quality fruit."

Potential Biological Controls

A comparative study of Trichopel (selected strains of *Trichoderma* spp., Agrimm Technologies, New Zealand) and Vaminoc (selected strains of *Glomus*, Agrimm Technologies) indicates Trichopel may help apple trees overcome replant disease. Vaminoc, applied at planting time, did little to overcome the disease, but it may prove more effective if applied prior to planting, which would give it the opportunity to establish mycorrhiza *before* exposure to replant disease. Field trials are currently under way to study Trichopel and Vaminoc further.

Calcium hydroxide was also investigated as an agent to combat replant disease, but its effects seemed to vary with soil pH levels. In two trials it was applied to three replant soils. The first pot trial was administered on an acidic soil (pH 4.5) where replant disease was not severe. This calcium hydroxide application eliminated the growth-retarding effect of apple replant disease. While the general trend of lowered growth retardation was seen in the second trial, the results were not statistically significant. This treatment is under further review in field studies.

The effects of mono ammonium phosphate (MAP) fertilizer was studied in pot trials, and the data showed it increased shoot growth. Using two orchard soils, the addition of MAP fertilizer to sterile soil resulted in a 20 percent increase in shoot length, while in nonsterile soil, shoot length increased 120 percent. These data imply that the addition of MAP fertilizer to nonsterile soil resulted in a more pronounced shoot growth response than that expected by nutrients alone. Additional studies are being conducted.

In the final set of pot trials, improved irrigation techniques could not overcome the symptoms of apple replant disease.

"A problem for the Australian apple industry," said Brown, "is the potential size of the market for a product against replant disease. Each year only about 100 ha of orchard are fumigated in all of Australia (including Tasmania), and this makes the cost of registration unattractive for chemical companies."

Phosphine's Corrosive Effects on Metals: Phase II Study Completed

The use of phosphine as an alternative to methyl bromide for fumigation in food processing and stored-grain facilities has been controversial. Phosphine's potential corrosive effects on metal and its chemical volatility have caused many to disavow its use as a fumigant, but others have embraced it as a viable alternative to methyl bromide.

The corrosiveness of phosphine is relative, dependant on its concentration, type of exposed metal, temperature, and relative humidity, among other variables. In the United States, all types of corrosion across all industries cost approximately $300 billion per year, according to the National Association of Corrosion Engineers.

Robert Brigham, consultant to the Environmental Bureau, Agriculture and Agri-Food Canada, recently completed a follow-up to his 1997–1998 study of the steady-state exposure of metals to phosphine. The study was partially funded by the USDA's Agricultural Research Service. By expanding the parameters of the first study—types of metals used, temperatures, phosphine concentrations, relative humidity, carbon dioxide levels, and exposure times—Brigham could more precisely predict the effect of phosphine on metals.

While corrosion of copper is directly related to the phosphine concentration and exposure time, the form of the surface deposits was quite a surprise. Brigham points out that, "sometimes the

surface deposits on the metal will be wet and sometimes dry." The type, or morphology, of surface deposit, is related to the relative humidity in the storage facility. Logically, a wet morphology would occur in high humidity conditions.

"The actual wet and dry morphologies occur counterintuitively. A dry morphology occurs in high relative humidity and wet morphology occurs in low relative humidity," according to Brigham. Wet surface deposits occur on copper exposed to more than 100 ppm phosphine at ambient temperatures if the relative humidity is less than about 50 percent. Higher relative humidity results in dry surface deposits on copper. Generally, surface deposits, either wet or dry, increase with phosphine concentration. Higher temperatures and longer exposures result in more surface deposits and more corrosion on copper.

With the ability to minimize its corrosion of metals, phosphine's effectiveness as a fumigant can be explored. Brigham's research suggests that conditions in a food processing and grain-storage facility can be manipulated to safely and effectively use phosphine. "The lab data fit well with controlled field exposures," says Brigham.

Brigham's results provide useful data for proprietors when deciding whether fumigation with phosphine is a viable option. David Mueller of Fumigation Service and Supply, Inc., Westfield, Indiana, feels the use of phosphine as a replacement fumigant for methyl bromide is commercially viable. "If phosphine concentrations are kept at low levels of 85–100 ppm and the temperature at approximately 35 °C, then phosphine is a viable alternative to methyl bromide."

Brigham also examined the effect of phosphine on electrical component parts of various types of machinery. While failures did occur, the components were found to be much more resistant to failure than expected. Forced failures of electrical components were achieved due to high contact resistance from buildup of nonconducting surface deposits, electrical shorting from the formation of wet surface deposits, and disruption of circuits due to the corrosion of metals. These failures occurred after extremes in relative humidity, phosphine concentrations, and repeated exposures were inflicted.

Mueller says, "this study is part of the puzzle of how phosphine can have niche uses as a replacement for methyl bromide. It provides the data that phosphine users have needed for years."

Midwest Strawberry Production Adapts to Plastic and Drip Tape System

Matted-row production of strawberries can move over in Kansas; the California strawberry production system that uses black plastic and drip irrigation is being successfully adapted for the Great Plains. So far, the system is working there just as well with or without methyl bromide.

Kansas State University Horticultural and Food Crops Research and Extension Specialist Alan Erb has been experimenting with the system for 3 years after seeing it successfully adapted in New Jersey and North Carolina. "We are finding that we are getting healthier plants, less disease, and keeping yield at the same level," Erb said.

In the traditional matted-row method for growing strawberries in Kansas, dormant crowns are planted in March, with 18 inches between plants and 48 inches between rows. In contrast, a system that has become the standard in California calls for soil to be mounded into rows and covered in black plastic, with a line of drip irrigation tubing between double rows. Plants are transplanted in early September in double rows 12 or 14 inches apart with 12 inches between plants. A floating row cover is added in early October and the strawberry plants are allowed to grow until late November.

When the row cover is removed, the plants go into winter dormancy. In early December, as with the matted-row system, they are covered with a thick layer of straw mulch and the row cover is reapplied. In March, the row cover and the mulch are removed, and the spring growing season begins.

The plastic and drip irrigation system does cost more than the matted-row method, due to the need for investing in specialized equipment and increased labor involved. But Erb points out that equipment costs are amortized over a number of years.

"And this system also allows plants to be harvested for 2 to 3 years before production begins to drop off rather than replacing them each year as is the current practice. This lets you recover some of the increased costs," he said.

To keep the plants producing for several years, they are cut back to the crowns right after harvesting ends in June. Not having to plug new plants each year offsets some of the increased labor required to put in this system, Erb pointed out.

Keeping the plants in production this way usually causes yield to increase but fruit size to drop. However, the reduction in size does not seem to be large enough to warrant re-establishing the beds every year.

The System Without Methyl Bromide

When Erb began working on adapting the plastic and drip irrigation method, he was not specifically considering it as a way of maintaining production without the use of methyl bromide. But given the impending ban, he felt it would be valuable to set up test plots both with and without methyl bromide as a soil fumigant before planting.

To get a basic reading on the system's response to disease and weeds, Erb compared standard soil applications of methyl bromide, 3 months of soil solarization before installing the black plastic, and no treatment. Solarizing took place in May through mid-August by laying down clear plastic in the exact location where the plants would grow.

Tests were run in the same plots in 1996 and 1998, with a fallow year in between. The plots were located in fields that had outbreaks of *Phytophthora parasitica* (the causal agent for Phytophthora root rot of tomatoes and peppers), "so it wasn't as if we were working on totally clean fields," Erb said. Verticillium wilt, leaf spot, and leaf blight can also be problems for Kansas strawberry growers.

Erb explained that the results can only be considered observational because he did not specifically inoculate disease organisms into the tests plots. He was interested in the system's potential to work without methyl bromide only as a sidelight to its practicality for strawberry production in the Great Plains.

Three years of data have shown no difference in yield between rows treated with methyl bromide or soil solarization or left untreated.

Having a break—a fallow time—rotating crops in the field, even planting a cover crop like marigolds, which are antagonistic to some soil nematodes, would also help minimize disease problems, he added. But Erb realizes that where the soil doesn't freeze as it does in the Midwest, a nonchemical pesticide system may not be as viable.

"If we combine some cultural practices—like this system, solarization, addition of compost, fallow times, and crop rotation—with disease-resistant cultivars, we could probably do without methyl bromide here except in fields that are notorious for disease problems," Erb said.

He believes it is important to look at how producers could manipulate the soil environment to grow strawberries without methyl bromide. "Research is not often able to examine long-term effects of a treatment. We need to look at production and soil condition 15 years down the road and see what is happening," Erb said.

But in the short term, Erb expects a chemical control is going to be a necessity for disease-susceptible cultivars, especially where the soil doesn't freeze or in fields that can harbor the fungi which cause root rot and vascular wilt diseases.

Husein Ajwa, a researcher at the ARS Water Management Research Laboratory in Fresno, California, has been at work with black, brown, and green plastic for weed control in a plastic and drip irrigation production system. He is also experimenting with direct application of pesticides other than methyl bromide directly through the drip irrigation system. (See Technical Report: Application of Methyl Bromide Alternative Fumigants by Drip Irrigation Systems for Strawberry Production in California, USDA Methyl Bromide Alternatives Newsletter, July 1999.)

Ajwa and his colleague Thomas Trout, research leader at the ARS lab, are taking advantage of an existing system of irrigation tape to directly apply a fumigant. The water in the irrigation system and the black plastic appear to minimize emissions from the fumigants.

In California, soil fumigation typically results in strawberry yields that are nearly double those from nonfumigated fields.

Weed Control: Case Studies in Flowers and Strawberries

Weed control in farm situations is a vexing problem. Until now, methyl bromide has handled the job admirably, but with the mandatory 50 percent reduction next year in the chemical's availability, alternatives must be found and

tested. Whereas methyl bromide was the fumigant for any number of crops and situations, life without methyl bromide will require different approaches for different crops to get effective weed control.

Soil solarization can be used as a preplant treatment for weed control and soil-borne pathogens, but must have the proper conditions, such as climate and high solar radiation. Some crops, such as high-quality flowers, are grown in climates not conducive to soil solarization, but could greatly benefit from its use.

Field-Grown Flowers

In an effort to increase effectiveness of solarization in the coastal regions of California, Clyde E. Elmore, extension weed specialist, Weed Science Program, University of California, Davis, conducted field studies to determine the effect of additives such as metham, ammonia, and some organic materials to the soil solarization process, as well as to examine the effectiveness of various types of coverings to improve solarization in the growing areas.

The use of metham in conjunction with soil solarization, at varying rates of 76 to 153 L/ha, increased weed control over soil solarization alone. The solution was applied using drip injection beneath the plastic tarp. This combination increased pest control over the same rates of metham alone. Ammonia at 459 L/ha injected into holes on 30-cm centers was not as effective, liter for liter, as metham. Organic materials may offer some increased effectiveness as an additive to soil solarization. Studies show that composted chicken manure at 7,250 kg/ha or 2,240 kg/ha of chopped broccoli covered with polyethylene increased control of some weeds over soil solarization alone in coastal sites.

While the studies show that chemical or organic additives to the soil solarization process increase weed control, these combinations are still not as effective for broad-spectrum weed control as methyl bromide.

Strawberries

One strategy to obtain effective weed control in strawberry crops is to enhance the efficacy of alternative fumigants to methyl bromide with the use of herbicides, in order to bolster the fumigants' weed control capacity.

S.A. Fennimore, extension vegetable weed control specialist, and S.J. Richard, both at the University of California, Davis, investigated several candidate herbicides at various planting stages on Camarosa and Selva strawberries. The site, near Salinas, California, was fumigated with 125 lb/acre of chloropicrin. This was followed 2 weeks later with pretransplant treatments of corn gluten meal at 300 lb/acre and 400 lb/acre and DCPA at 9 lb/acre. Two days later, the strawberry cultivars were transplanted in a 52-inch bed with two rows per bed—one row of each variety.

The corn gluten meal and DCPA produced little or no crop injury and had no adverse effects on plant diameters or crop biomass. Corn gluten meal, at the 400 lb/acre concentration, reduced annual bluegrass by 54 percent but provided no control of shepherdspurse, clover, or corn spurry. DCPA provided 100 percent control of annual bluegrass and corn spurry, but had no effect on shepherdspurse or clover.

In evaluating candidate herbicides for post-transplant use, two rates of each of the following were tested: carfentrazone (0.075 and 0.15 lb/acre), cloransulam (0.0156 and 0.0313 lb/acre), dimethenamid (0.94 and 1.2 lb/acre), flumioxazin (0.063 and 0.125 lb/acre), halosulfuron (0.032 and 0.047 lb/acre), isoxaben (0.5 and 1.0 lb/acre), rimsulfuron (0.0156 and 0.0313 lb/acre), and sulfentrazone (0.175 and 0.25 lb/acre). Napropamide was tested at 4 lb/acre only.

The following treatments resulted in acceptable crop injury and had no effect on plant diameters or biomass: carfentrazone at 0.075 lb/acre, sulfentrazone at 0.175 lb/acre and 0.25 lb/acre, and isoxaben at 0.5 lb/acre. Marginally acceptable crop injury was shown with the use of carfentrazone at 0.15 lb/acre, napropamide at 4 lb/acre, and flumioxazin at 0.063 lb/acre. Due to unacceptable crop injury, cloransulam, dimethenamid, halosulfuron, and rimsulfuron were eliminated as candidates.

Of the five candidate herbicides with marginal or acceptable tolerance by strawberries, carfentrazone at 0.075 lb/acre provided 100 percent control of shepherdspurse, 40–77 percent control of annual bluegrass and corn spurry, and no control of clover; napropamide at 4 lb/acre and sulfentrazone at 0.25 lb/acre provided 100 percent control of annual bluegrass and corn spurry, 73 percent control of clover, and 67 percent control of shepherdspurse; isoxaben at 0.5 lb/acre provided 100 percent control of clover, corn spurry, and shepherdspurse and 31 percent control of annual bluegrass, flumioxazin at 0.063 lb/acre provided 100 percent control of annual bluegrass, clover, and corn

spurry and 73 percent control of shepherdspurse.

Delayed post-transplant applications of isoxaben at 0.25 lb/acre and triflusulfuron at 0.0156 and 0.0313 lb/acre were made 3 weeks after transplanting with little or no crop injury. All other treatments resulted in unacceptable crop injury or significant reduction in plant diameter or biomass. Triflusulfuron at 0.0313 lb/acre provided 100 percent control of annual bluegrass and shepherdspurse and 70 percent control of clover and corn spurry. Isoxaben at 0.25 lb/acre resulted in 100 percent control of annual bluegrass, clover, and corn spurry and 73 percent of shepherdspurse.

According to Fennimore, weed control with these compounds is not as reliable as methyl bromide. "Currently registered herbicides are not adequate as replacements for methyl bromide," he says. "There is a need to identify new herbicides."

Of the registered herbicides examined in his study, Fennimore feels sulfentrazone works best as a pretransplant and immediate post-transplant herbicide, with little negative effect on plant stand, and no negative effect on plant diameter or biomass. Triflusulfuron, according to Fennimore, has the greatest potential for use as a delayed post-transplant herbicide.

More studies are needed to evaluate the merits of carfentrazone, flumioxazin, isoxaben, and sulfentrazone as pretransplant or immediate post-transplant herbicides, and triflusulfuron as a delayed post-transplant herbicide in strawberries.

Integrated pest management, at least for now, will need to be employed by some growers to create an effective alternative.

Technical Reports

Efficacy of Fumigation of Empty Ship Holds With ECO_2FUME, the Horn Generator or Methyl Bromide With Recapture

Paul Fields[1] and Sheila Jones[2]

1. Agriculture and Agri-Food Canada, Cereal Research Centre, 195 Dafoe Rd., Winnipeg, MB, R3T 2M9, Telephone: 204-983-1468, Email: pfields@em.agr.ca
2. Agriculture and Agri-Food Canada, Policy Branch, Environment Bureau, 930 Carling Ave., Ottawa, ON, K1A 0C5, Telephone: 613-759-7300, Email: jonessh@em.agr.ca

Why Investigate Alternatives to Methyl Bromide for Ship Hold Fumigations?

The Montreal Protocol presently exempts the use of methyl bromide for quarantine and pre-shipment purposes. The use in this sector is growing. This exemption, however, was one of the main topics of discussion at the Meeting of the Parties in Cairo in 1998, and again at the Open Ended Working Group meeting in Geneva. The definitions for quarantine and pre-shipment are unclear, and there is apparent abuse of this exemption. In particular, the pre-shipment exemption is the most contentious.

Members of the Canadian Industry/Government Working Group on Methyl Bromide Alternatives believe that an investigation into alternatives for ship hold applications would demonstrate the effectiveness of potential alternatives that are either currently registered or not registered for use in Canada, and their associated costs. Furthermore, these techniques may be useful in other situations where methyl bromide is used to control insect infestations.

Methods

The test was conducted on lake-going ship, the "Canadian Trader", that has six holds, 5000 to 7000 m^3 each. There were four treatments: methyl bromide at approximately 16 000 ppm (21 oz/1000 ft^3) with recapture after one day (hold 1), phosphine at 500 ppm applied using the ECO_2FUME ™ method (hold 4), phosphine at 1000 ppm applied using the Horn Generator using magnesium phosphide (Magtoxin® Granules) (hold 6), and an untreated control (hold 3). To recapture the methyl bromide, the air from the ship hold was passed over a molecular sieve, a technique developed by Cryo-Line Supplies Inc. ECO_2FUME™ is 2% phosphine with 98% carbon dioxide in pressurized cylinders, and is produced by Cytec Canada Inc. The Horn Generator produces phosphine by mixing magnesium phosphide with water, and is produced by Degesch America Inc.

Four insect species were used in the bioassay: rusty grain beetle (*Cryptolestes ferrugineus* (Stephens)), rice weevil (*Sitophilus oryzae* (L.)), red flour beetle (*Tribolium castaneum* (Herbst)), and the lesser grain borer (*Rhyzopertha dominica* (Fabricus)). Twenty-five adults were held in plastic vials with screen tops containing wheat for several days before fumigation. Hence all vials contained both eggs and adults in the same vial.

Vials were taped to a rope, with 12 vials per species for each rope.

Three ropes were hung from the manhole access to the hold, and one rope was pulled from each hold 32, 48 and 72 h after the beginning of the fumigation. For the methyl bromide treatment there was only one rope, and it was pulled at the completion of the methyl bromide fumigation, 32 h after the beginning of the fumigation. Temperatures were measured using thermocouple wires taped to the ship hold and the vials in each of the holds at the bottom, middle and top levels.

After removing a rope from a hold, adults were sieved out of the wheat from each vial, survival noted and the adults placed on clean wheat. After one week the number of live and dead adults was assessed a second time to detect delayed mortality or revival of insects that could have been counted as dead but were in a fumigant-induced stupor. To assess the survival of the eggs, the wheat that was held in the ship holds was placed at 30°C for five weeks and the number of emerged adults counted.

Results

Temperatures in the ship holds varied between a high of 33°C to a low of 15°C during the three days of the test, with an average temperature during the first day of fumigation of 23°C. The target gas concentrations were reached at all three levels after 9 h for methyl bromide, 1 h for ECO$_2$FUME™ 500 ppm phosphine application and 5.5 h for Horn Generator at 1000 ppm phosphine. Some phosphine was detected in the untreated hold at the bottom level, but it was never greater than 11 ppm.

After 32 h, none of the adult insects survived in any of the three fumigation treatments. In the untreated hold there was not more than 2% adult mortality for any of the species. After one week, none of the insects in the fumigated holds had revived, and the mortality of insects taken from the untreated hold was not more than 5% for all species, except lesser grain borer which had an average mortality of 31±8% (mean±SEM). The emergence of adults from infested grain in the untreated hold varied between insects (Table 1). Given the low emergence for rusty grain beetles from the untreated samples, it was impossible to estimate the mortality due to fumigation. For the other insects, there was less than 7% survival of eggs after 32 h in the fumigated holds and less than, 1% survival after 48 h and no survival after 72 h (Table 1).

Discussion

All three of the methods tested in this trial have potential for reducing methyl bromide emissions resulting from empty ship fumigations. These methods could be scaled up for treating entire ocean-going vessels which have capacities ranging from 30 000 to 100 000 m^3. Larger recapture units would have to be built. This may be addressed in part by reducing the volume needed to fumigate, and hence the total amount of methyl bromide by inflating balloons in the holds.

The temperatures during this trial were warm. Ships often need to be fumigated in cooler weather. Phosphine efficacy is reduced more by low temperatures then is methyl bromide efficacy. Higher phosphine concentrations do increase mortality, however, higher concentrations cannot entirely compensate for shorter durations, ie doubling the concentration will not half the time needed for control. Ships are heated for painting, and this technique could be used to preheat ships before a phosphine fumigation, and this may increase the effectiveness of the fumigation.

Another solution to infested empty ships would be to treat the grain as it is loaded into ships with a residual insecticide such as malathion or diatomaceous earth, or to fumigate the grain in-transit with phosphine after the grain had been loaded. However, this approach would require a change in policy and possibly require a change in legislation before these methods could be used to deal with the problem of infested ship holds, in Canada.

All three of these methods could easily be adapted for shipping containers, and some tests with the recapture had already demonstrated its effectiveness. Another hurdle for the phosphine-based methods would be the certification that the control is sufficient for quarantine purposes, as most importing countries only recognize methyl bromide as adequate for quarantine treatment.

Acknowledgments

This was a collaborative study that would not have been possible without the help of the following people: Pierre Beauchamp, Denis Bureau, Roger Cavasin, Geoff Cuttin, Nancy Kummen, Dorothy Laidlaw, Brett MacKillop, Bernie McCarthy, John McIssac, Mike McLean, Micheal Maheu, Mark Matthews, Dave Meuller, Stephen Murch, Don Shaheen, Martin St-Pierre, Blaine Timlick, Alan Van Ryckeghem and Murray Weightman.

Table 1. The survival of eggs in treated ship holds as compared to eggs in untreated ship hold as measured by emerging adults after 5 weeks of incubation at 30°C.

Duration of exposure (h)	Insect	Adults emerged/vial, untreated hold (mean±SEM)	Survival as compared to untreated hold (%)		
			Methyl Bromide	ECO_2FUME^{TM} PH_3 500 ppm	Horn Generator PH_3 1000 ppm
32	Red Flour Beetle	11±1	0.9	0.0	0.0
	Rice Weevil	69±6	0.0	3.0	1.1
	Lesser Grain Borer	70±7	0.0	6.4	3.4
	Rusty Grain Beetle	0.1±0.1	—	—	—
48	Red Flour Beetle	14±2	—	0.0	0.0
	Rice Weevil	55±5	—	0.0	0.0
	Lesser Grain Borer	106±10	—	0.4	0.3
	Rusty Grain Beetle	0.1±0.1	—	—	—
72	Red Flour Beetle	11±1	—	0.0	0.0
	Rice Weevil	96±3	—	0.0	0.0
	Lesser Grain Borer	107±13	—	0.0	0.0
	Rusty Grain Beetle	0.3±0.2	—	—	—

Additional information is available at:

Full version of this report:
www.agr.ca/policy/environment

United Nations' Methyl Bromide Technical Options Committee 1998 Report
www.teap.org/html/methyl_bromide_reports.html

Methyl bromide recapture: METBRO Technologies Inc.
Bernie Comella, 702-429-7196, bcomella@ntsdev.com, www.metbro.com

Horn Generator: Degesch America Inc
Mark Mathews, 804-231-1000, mfmathews@erols.com, www.degeschamerica.com

ECO_2FUME ™ : Cytec Canada Inc
Roger Cavasin, 905-374-5828, Roger_Cavasin@WE.cytec.com, www.cytec.com

Propargyl Bromide and Other Fumigants for Nematode Control

J.W. Noling[1] and J.P. Gilreath[2]
University of Florida, Institute of Food & Agricultural Sciences
[1]Citrus Research & Education Center, 700 Experiment Station Rd., Lake Alfred, FL 33850
[2]Gulf Coast Research & Education Center, 5007 60th St. E., Bradenton, FL 34203

Although early stage field and laboratory investigations showed promising results as a broadspectrum fumigant for soilborne pest control (patent application results, 1953), propargyl bromide was apparently never fully pursued because of the explosiveness of the compound and because of the manufacturing cost differential between propargyl bromide and methyl bromide (methyl bromide is, after all, a waste product of the halogen fire extinguishers). In contrast, field research at the CREC Lake Alfred was initiated with the assumption that propargyl bromide would not ultimately be characterized as an ozone depleting substance and that formulation problems contributing to its explosiveness could be resolved. Cost factors were not a consideration. To reduce or eliminate the explosive nature of propargyl bromide, it is currently formulated with toluene (20%). Given that toluene is a known carcinogen, an alternative stabilizer will undoubtedly be required to survive the registration process. Soil-borne pest and disease control in Florida tomato production had been achieved for over 25 years with the broadspectrum soil fumigant methyl bromide. The objectives of the studies reported herein were to evaluate the use and efficacy of various alternatives as preplant soil treatments for control of the southern root-knot nematode, *Meloidogyne incognita*, yellow nutsedge, *Cyperus esculentus*, and to measure resultant impacts on tomato plant growth, development, and yield.

Table 1. Influence of various soil fumigant treatments on nutsedge germination, tomato yield, M. incognita final harvest soil population density and root gall severity in field microplots, CREC, Lake Alfred, FL, Spring 1999.

		SPRING 1999			
TREATMENT	Application Rate /Treated Acre	NUTSEDGE GERMINATION of 5 planted	TOMATO YIELD (G/PLANT)	ROOT GALL SEVERITY (0-10)	SOIL DENSITY/ 100 cc SOIL
1. BASAMID	400 lb /a	—	5832.3 b	2.94 b	1442.8 ab
2. PROPARGYL BROMIDE	150 lb/a	0.025 b	6766.8 a	0.9 c	779.8 b
3. PROPARGYL BROMIDE	300 lb/a	0.025 b	6662.7 ab	0.2 c	8.3 b
4. TELONE C-17	35 gal/a	—	6912.1 a	0.4 c	133.4 b
5. NEMATODE FREE CONTROL	methyl bromide 400 lb/a	—	6513.4 ab	0.9 c	227.7 b
6. UNTREATED CONTROL	—	4.33 a	2644.7 c	7.9 a	5608.7 a

Data are means of nine replications of one plant each.
Means within columns followed by the same letter are not significantly different according to Fishers's LSD Procedure ($P<0.05$).
Root Gall index based on portion of root system covered using 0-10 rating (Zeck, 1971)
Nematode population density are numbers per 100 cc soil. Actual data are presented, but data were transformed to log 10(n+1) for analysis.

During the spring of 1999, a single replicated field experiment was conducted to compare nematode control and tomato yields in response to broadcast equivalent propargyl bromide application rates of 150 and 300 lb/a compared with Basamid (400 lb/a), methyl bromide 98/2 (400 lb/a), Telone C17 (35 gal/a), and an untreated control. Propargyl bromide and Telone C17 soil injections were made using a Hamilton Gas Tight syringe installed with a 25 cm-long stainless steel needle. After a two week soil aeration period, tomato plants were grown to maturity and harvested twice. At each harvest fruit was sorted and weighed into three size categories including medium, large, and extra large tomatoes. Following harvest, these same plants were cut at the soil line and the foliage weighed. Immediately after foliage removal the plants were uprooted and the root systems evaluated for root gall severity based on a visual rating scale of zero to ten. Final soil population density samples were then removed after root gall assessment.

The results of this study showed that all fumigant treatments significantly (P=0.05) reduced final harvest soil population density of *Meloidogyne incognita* and tomato root gall severity compared to the untreated control. No differences (P=0.05) or dose response relationship between application rates of propargyl bromide, Telone C17, or methyl bromide were observed in these parameters. Tomato yields were significantly (P=0.05) increased by all fumigant treatments compared to the untreated control. Both propargyl bromide (150 lb/a) and Telone C17 increased (P=0.05) tomato yields compared to the Basamid treatment. In summary, propargyl bromide proved to be a compound which was easy to handle and apply, demonstrated excellent nematicidal and herbicidal activity, and produced tomato yields equal to or superior to that of methyl bromide.

Field research with propargyl bromide is continuing, however other factors and regulatory concerns must be addressed before being realistically considered a potential alternative to methyl bromide. In addition, to effectively reduce field application rates of propargyl bromide because of cost considerations may require the coapplication (synergism) of other fumigants such as chloropicrin. In this regard, future field testing may require further expansion. Methyl bromide is commonly used with chloropicrin when soilborne disease constitutes a problem. This suggests that future testing of propargyl bromide should be done in combination with chloropicrin.

Hot Water Immersion Alternative to Methyl Bromide Fumigation of Limes

W.P. Gould and R.G. McGuire, USDA–ARS, Subtropical Horticulture Research Station, Miami, Florida

Mealybugs are major pests of many agricultural commodities. Limes which are imported into the United States from the Bahamas are inspected for mealybug pests. When unidentifiable early stages, or actionable species of mealybugs are found, limes are fumigated with methyl bromide. This quarantine treatment is necessary to prevent spread of new pests which do not occur in the United States. During cold weather, higher doses are required, which cause injury to the limes. Alternative treatments for commodities infested with hitchhiker pests are required, to prevent interruptions in commerce. The mealybugs found in this study were identified as *Planococcus citri* Risso (50%) and *Pseudococcus odermatti* Miller & Williams (50%).

A number of possible treatments were considered, including insecticidal coatings. Tests with coatings did not reach the high pest mortality necessary for a quarantine treatment. Hot water was found to be the most likely alternative to replace methyl bromide in this case. Hot water has been used to disinfest commodities of a variety of surface pests including mealybugs. Hot water treatment fits well as a rapid treatment on a packing line. It was proposed that a hot water treatment in the range of 46–57°C for 5–20 minutes would disinfest the surface of the limes of pests. The pest insects are not allowed into the United States so limes were treated at the port of entry, held and examined for pest mortality, then returned to their origin for disposal.

Preliminary tests indicated that limes would tolerate 49°C for up to 15 minutes without showing damage, so this temperature was chosen for the dose/mortality study. Limes with feral mealybug populations were dipped in 49°C ± 0.5°C hot water for times of 1 to 16 minutes. Limes were removed from hot water and hydrocooled at 25°C ± 2°C for 10 min. The limes were then held for 2–3 days at 24°C ±2°C. Limes were then examined under a stereo-microscope for insect mortality. An untreated control was used to assess natural mortality.

Hot water treatment of limes showed little effect on insect mortality until 5 minutes, then mortality increased linearly until no survivors were recovered after 12 min of treatment. Statistical analysis gave 99.9968% mortality (probit 9) predictions of 21 and 13 minutes. We chose 20 minutes at 49°C as a conservative treatment which would have no survivors and initiated a large scale test with groups of 1,200 fruit. The test was continued until over 1,000 mealybugs had been treated and killed with no survivors. During this test over 7,200 limes were treated with 1,308 insects killed and no survivors.

The effect of short hot water dips on lime quality was also studied. Limes were immersed for 10, 15, or 20 minutes in water at 46, 49, and 52°C. One group of fruit was not treated and served as a control. All fruits were cooled in water at about 24°C for 10 minutes after hot water immersion. All fruits were weighed initially. Control fruits were measured for color, firmness, pH, % acids, % solids, and ascorbate. Treatment and control fruits were measured for these characters after 10 days storage at about 24°C. This experiment was repeated four times and data were analyzed using analysis of variance.

The temperature of the hot-water treatment and the time of immersion significantly affected the fruit quality. Treatment at 52°C was significantly more damaging than treatment at 46 or 49°C. At 52°C injury and weight loss were greatest, and the fruits were less firm. The fruit color was lighter, more intense, and less green, and the pH of the juice and acidity increased slightly. The effect of treatment time was less significant. Firmness and juice characteristics were not affected by time of treatment between 10 and 20 minutes at these temperatures. Injury and weight loss were greater after a 20 minute treatment, and surface color was lighter, more intense, and less green with increasing time. Treatment at 49°C for 20 min did not significantly affect quality when treated fruit were compared with untreated control fruit.

The 20 minute 49°C hot water immersion treatment was effective in killing mealybugs and all other arthropods found externally on limes, or under the calyx in this study. We did not see any surviving insects or mites after the 20 min treatment. This treatment is comparable to 10 minutes immersion in 49°C hot water for two scale insects on fruit and 12 minutes immersion in 49°C water eliminated 95% of ants, aphids and mealybugs on red ginger flowers in Hawaii. Also the longtailed mealybug required an estimated 19 minutes to reach 99% mortality on persimmons dipped in 49°C hot water in New Zealand. Fuller rose beetle eggs were killed by 8 minutes at 52°C in a California test on lemons. Researchers in New Zealand found that two spotted spider mites were more resistant to heat and required 40 minutes at 48°C to reach 99% mortality.

The treatment time of 20 minutes is conservative and is based on the theoretical prediction of survivors if large numbers of insects are treated. It has been shown that long hot water treatments damage some citrus, but limes in this study tolerated the relatively short 20 minute treatment with no loss in quality. We intend to conduct further work with mealybugs to expand the range of temperatures that can be used to treat commodities. We feel that hot water is a technologically simple and robust technique which may be valuable for other commodities as well as limes.